The NASA Land Cover Land Use Change (LCLUC) Program Activities

Chris Justice, LCLUC Project Scientist, Dept. of Geographical Sciences, University of Maryland

Garik Gutman, LCLUC Program Manager, NASA Headquarter

Krishna Vadrevu, LCLUC Deputy Program Manager, Marshall Space Flight Center

International Meeting on Air Pollution in Asia – Inventories, Monitoring and Mitigation, Hanoi, Feb. 2023

LCLUC Silver Jubilee 2022

Fires

Deforestation

Urban changes

Agriculture

Foundations

1990 NASA Landsat Pathfinder initiated (UNH, UMD, GSFC)
1990 IGBP-DIS – global data sets (inc. 1km Land Cover)
1994 IGBP/IHDP LUCC officially launched (Skole, Chair)
1996 NASA Created LCLUC Program
1997 First LCLUC Science Team Meeting

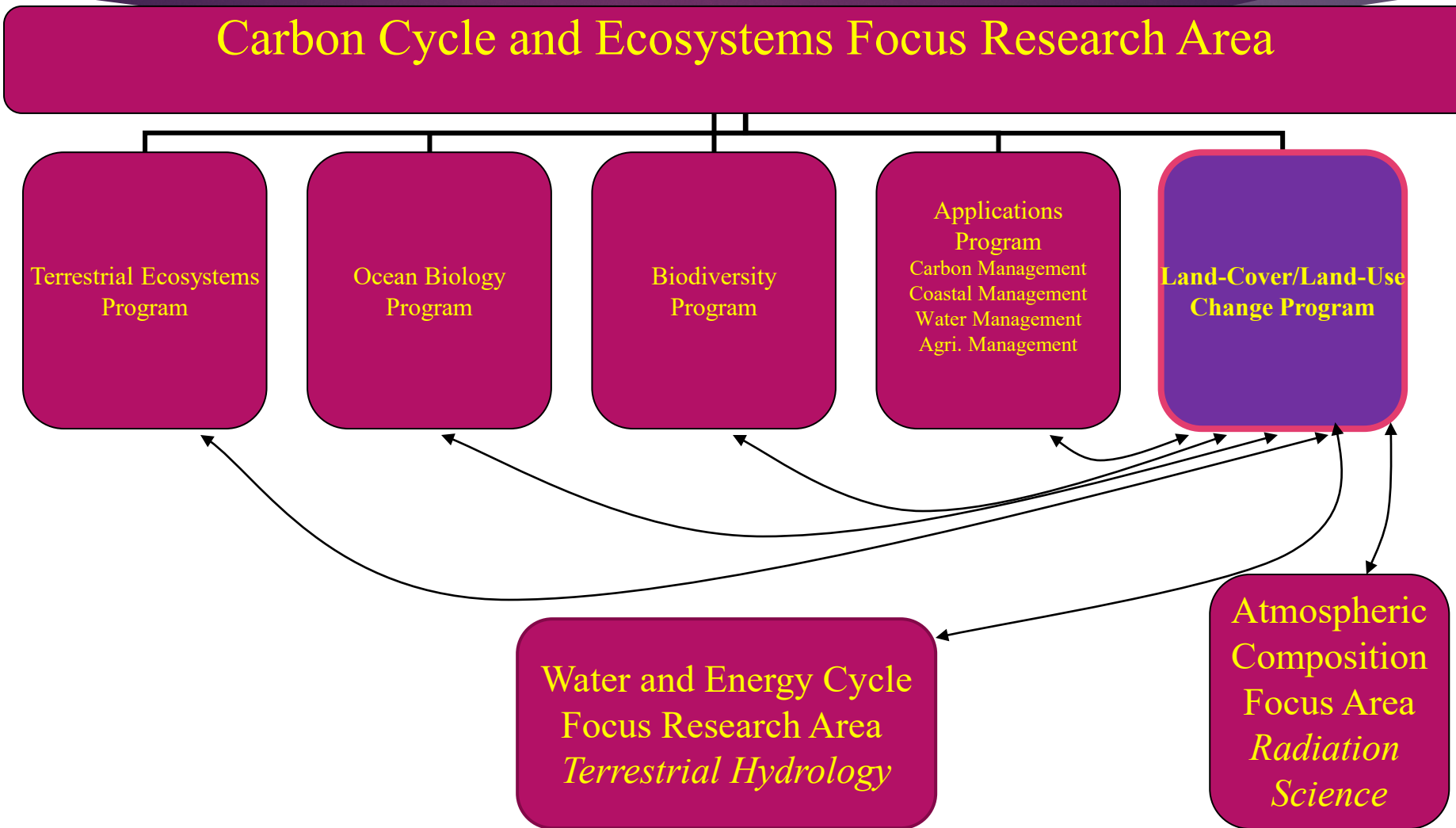
LCLUC Program Goals

… FURTHER THE UNDERSTANDING OF THE CONSEQUENCES OF LAND USE CHANGE FOR CONTINUED PROVISION OF ECOLOGICAL GOODS AND SERVICES, SUSTAINABLE LAND MANAGEMENT AND HUMAN WELL BEING

ULTIMATE VISION …TO DEVELOP THE CAPABILITY TO PERFORM REPEATED INVENTORIES OF LU LC FROM SPACE AND DEVELOP THE SCIENTIFIC UNDERSTANDING AND MODELS NECESSARY TO EVALUATE THE CONSEQUENCES OF OBSERVED CHANGES.

LAND USE IS CENTRAL TO A NUMBER OF ENVIRONMENTAL, SOCIETAL AND POLICY CHALLENGES – CLIMATE CHANGE, SUSTAINABLE DEVELOPMENT, FOOD SECURITY, BIODIVERSITY LOSS

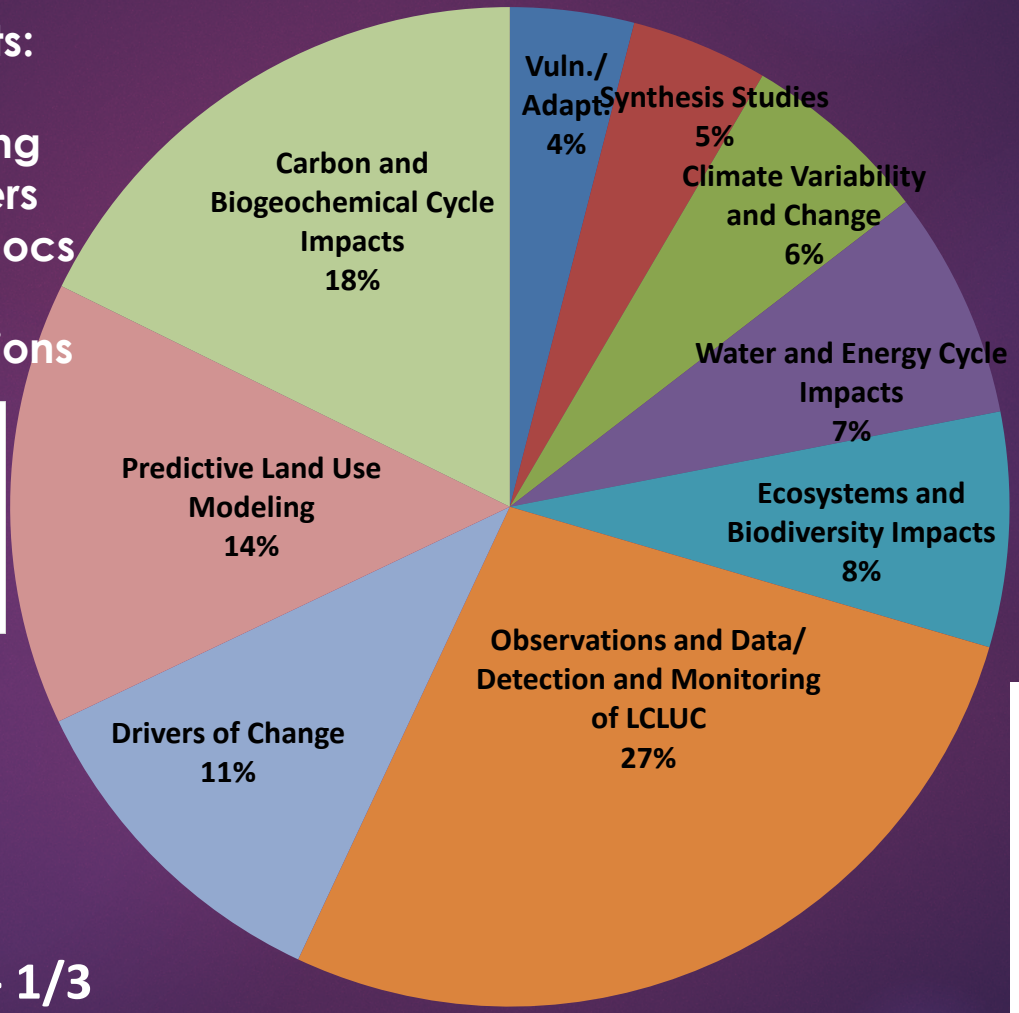
WHERE LCLUC FITS WITHIN NASA

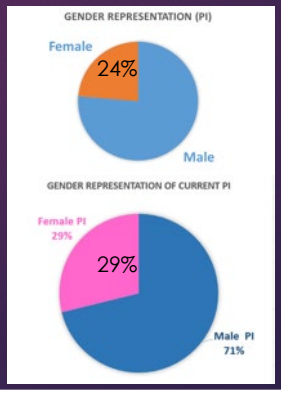


LCLUC Program Content

25-yr Program stats:

- >300 projects
  - ~50 ongoing
- >800 researchers
  - >20 post-docs
  - >50 grads
- >1000 publications





Monitoring - 1/3
Impacts - 1/3
Synthesis, other - 1/3

http://lcluc.hq.nasa.gov

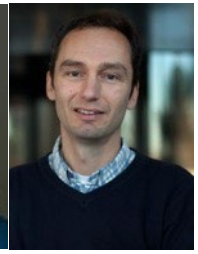
The Role of Social Science

- **The study of land use requires an interdisciplinary approach combining physical and social sciences**
- **The Human Dimension has an important role in LCLUC**
- **Social and Economic science research includes**
  - **impacts of changes in human behavior policy and economy on LCLUC**
  - **impacts of Land Use and Cover Change on society**
  - **mitigation and adaption to climate change of land-use systems**
- **The Socio-Economic component is often a mandatory part of all LCLUC proposals – unique within NASA**

25 Years of External Program Linkages: International

- **Global Observations of Forest Cover and Land-use Dynamics (GOFC- GOLD) since 1997**
  - **Fire Implementation Team office at UMD funded by LCLUC**
  - **Regional Information Networks coordinated by START**
- **IGBP/IHDP LUCC → GLP**
  - **Global Land Program (GLP) forum for international Land Use Science**
  - **GLP Secretariat is moving to the University of Maryland**


Ariane de Bremond


Peter Verburg

- **EARSeL (EU Remote Sensing Labs)**
  - **LULC Special Interest Group**
    - **Joint biennial workshops**
- **CEOS/GEO**
  - **•International Working Group on Calibration and Validation**
  - **•Land Surface Imaging (LSI) Constellation Working Group**
  - **•GEO Global Landcover Datasets**
  - **•GEO GEOGLAM Agricultural Monitoring**
- **Space Agencies**
  - **ESA**
  - **VNSC, GISTDA, ISRO, JAXA, PHILSA**
  - **Worldwide**


Ioannis Manakos


Francesco Sarti

25 Years of GOFC-GOLD Program Support

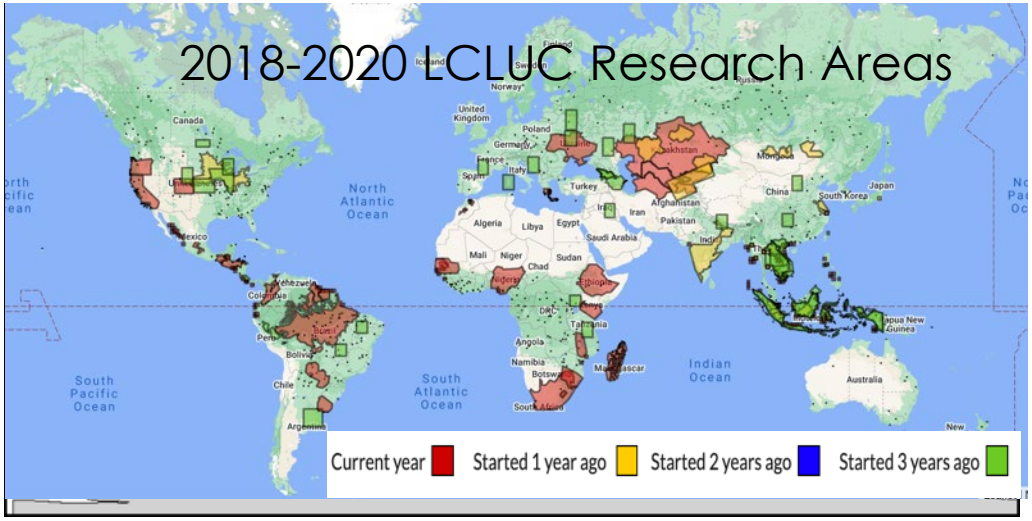
St. Petersburg, Russia, 2001

Former GOFC-GOLD Chair
John Townshend, U. Maryland

"GOFC-GOLD Fellowships for **Data Training** and the Advanced Training Institute on Key GOFC-GOLD Themes", April-May 2012,July-August 2014 Sioux Falls , SD and Boston, MA

Curtis Woodcock
Boston U.

Former GOFC-GOLD Networks Coordinator,
Olga Krankina,
Oregon State U.



LCLUC Support of Chairs

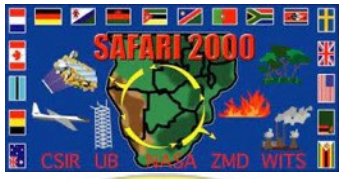
- John Townshend
- Tony Janetos
- Chris Justice

- LCLUC Support of the Fire IT Office@UMD; @MSU and the Land Cover office @MSU
- LCLUC Support of Regional Networks via START

Current GOFC
Networks Coordinator,
Krishna Vadrevu,
NASA MSFC

LCLUC International Regional Initiatives

- **SAFARI (South Africa)**



- 3-year project, began in August 1999
- studied the environment of southern Africa
- LCLUC: burning of African forests & savanna
- Goal: to explore how emissions affect phenomena ranging from regional crop productivity to global climate change.

- **LBA (Amazon)**

- Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA): 1998-2006
- LBA-Eco: Field campaign in several sites to help answering questions on forest conversion, re-growth, selective logging, and the sustainable land use in Amazonia

- **NEESPI (Northern Eurasia)**

- The Northern Eurasia Earth Partnership Initiative (NEESPI) 2006-2016.
- Currently, Northern Eurasian Future Initiative (NEFI) a regional component of Future Earth

- **MAIRS (Monsoon Asia)**

- The MAIRS programme (Monsoon Asia Integrated Regional Study) 2006-2016
- Currently, Monsoon Asia Integrated research for Sustainability - part of Future Earth

- **SARI (South/Southeast Asia)**

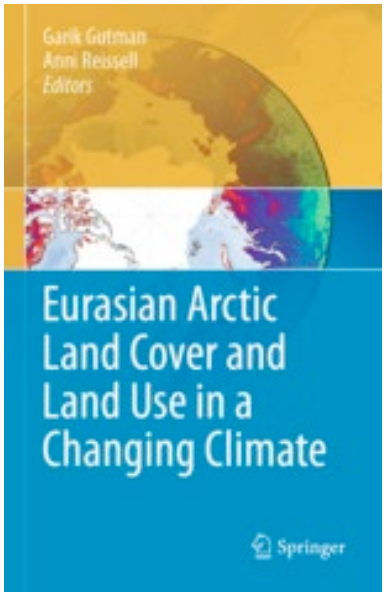
- South/Southeast Asia Research Initiative (SARI) 2014-2024
- LCLUC interactions on climate, water resources, biodiversity, atmosphere, vulnerability, impacts and adaptation issues

International Regional Science Team Meetings Last 15 years

NEESPI-LCLUC Science

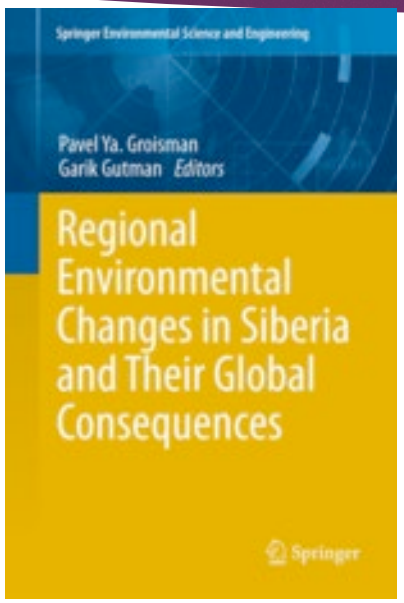
NEESPI: Northern Eurasia Earth Science Partnership Initiative

NEESPI → NEFI (Northern Eurasia Future Initiative)



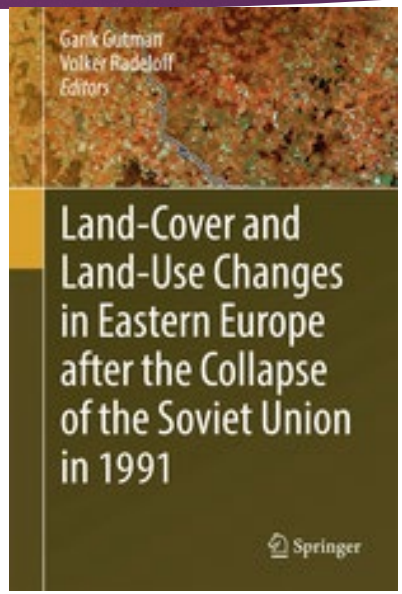
Springer 2010

Arctic



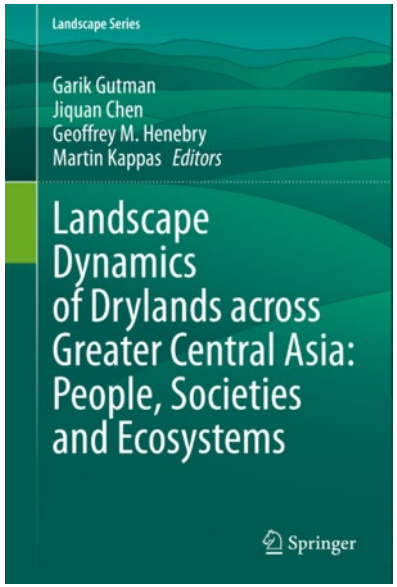
Springer 2012

Siberia



Springer 2017

Eastern Europe



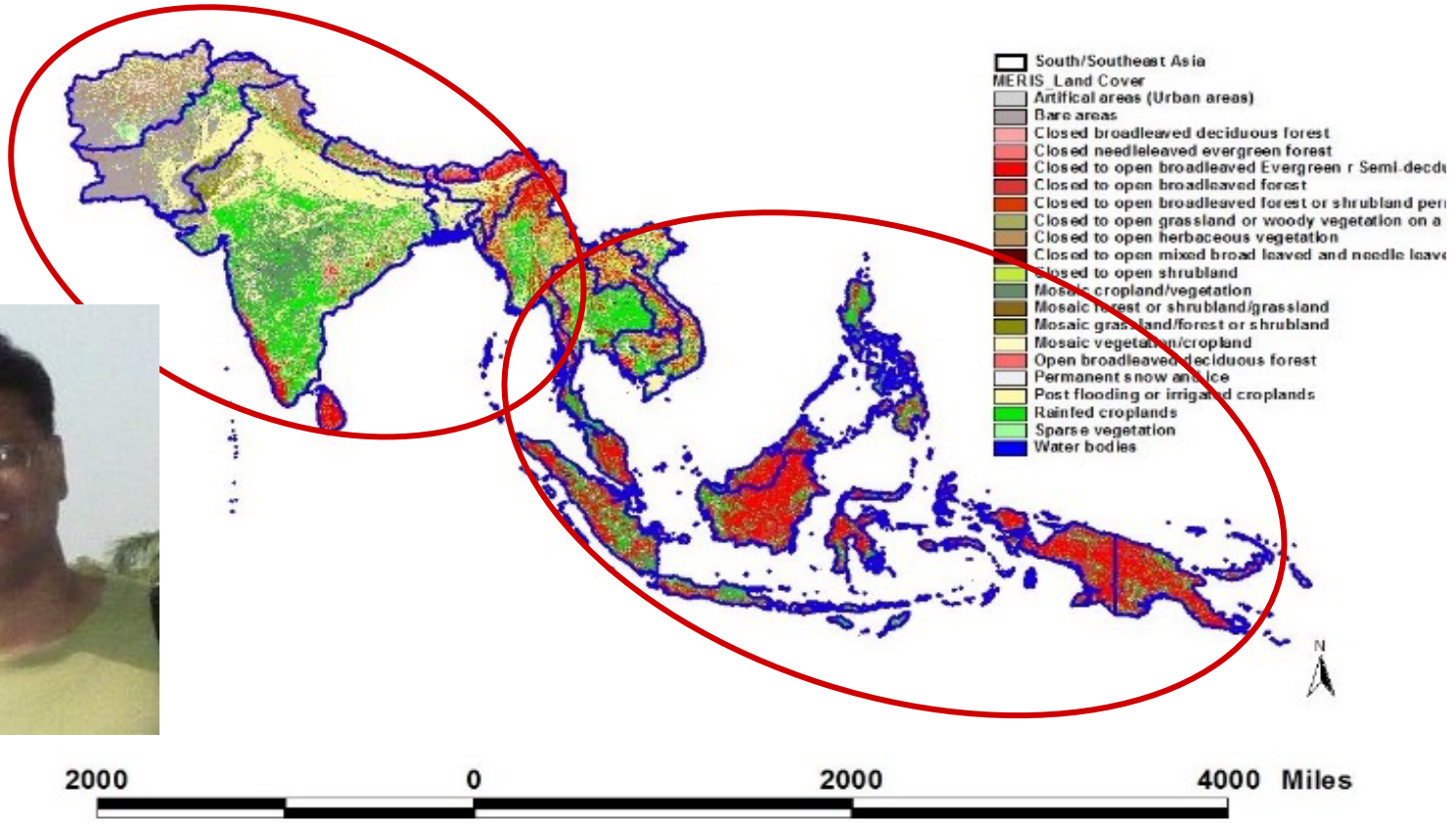
Springer 2020

Central Asia

> 750 scientists from 200 institutions in 30 countries with > 170 projects
80 Ph.D. students

>1500 papers

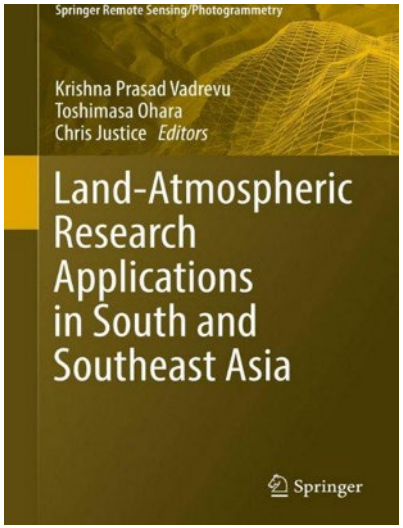
South/Southeast Asia Research Initiative: SARI



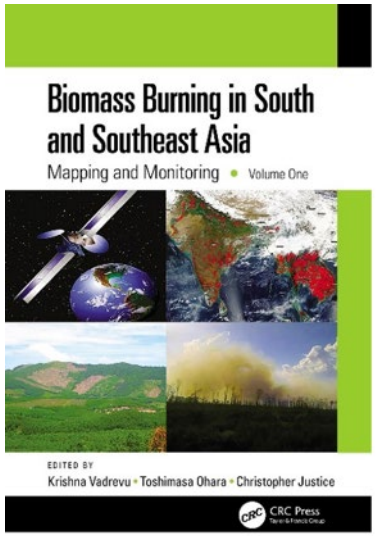
NASA-SARI Science

- LCLUC-2015: South Asia
- LCLUC-2016: Southeast Asia
- LCLUC-2018: All Asia
- LCLUC – 2021 SARI Synthesis

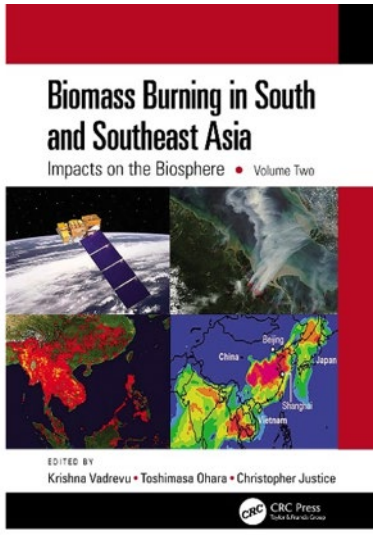
- > 250 scientists
- >150 institutions
- 15 countries
- > 25 projects
- >250 papers
- 12 special issues



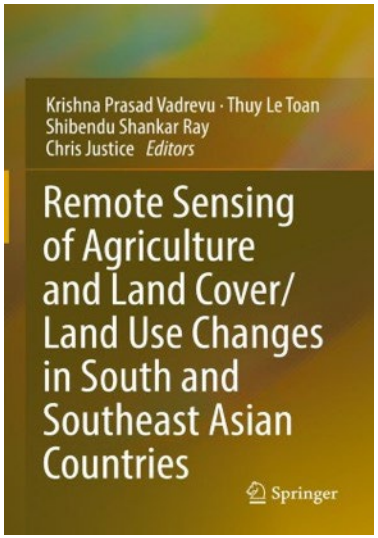
Springer 2018



CRC Press, 2021



CRC Press, 2021



Springer 2022

25 years of International LCLUC Capacity Building

- **Trainings in conjunction with regional LCLUC meetings since 2009**

Promoting EO-based science, data, products and RS methods

  - NEESPI
    - NASA-ESA Trans-Atlantic Training (TAT) for students in Eastern Europe

Francesco Sarti, ESA

Pre-TAT LCLUC Training in Latvia - 2010 Czech trainees
Premek Stych, Charles U., Prague

8 TATs since 2013

  - **SARI**

Krishna Vadrevu, NASA MSFC

- **Trainings in South/SE Asia**
  - In collaboration with JAXA, GISTDA, VNSC, NIES

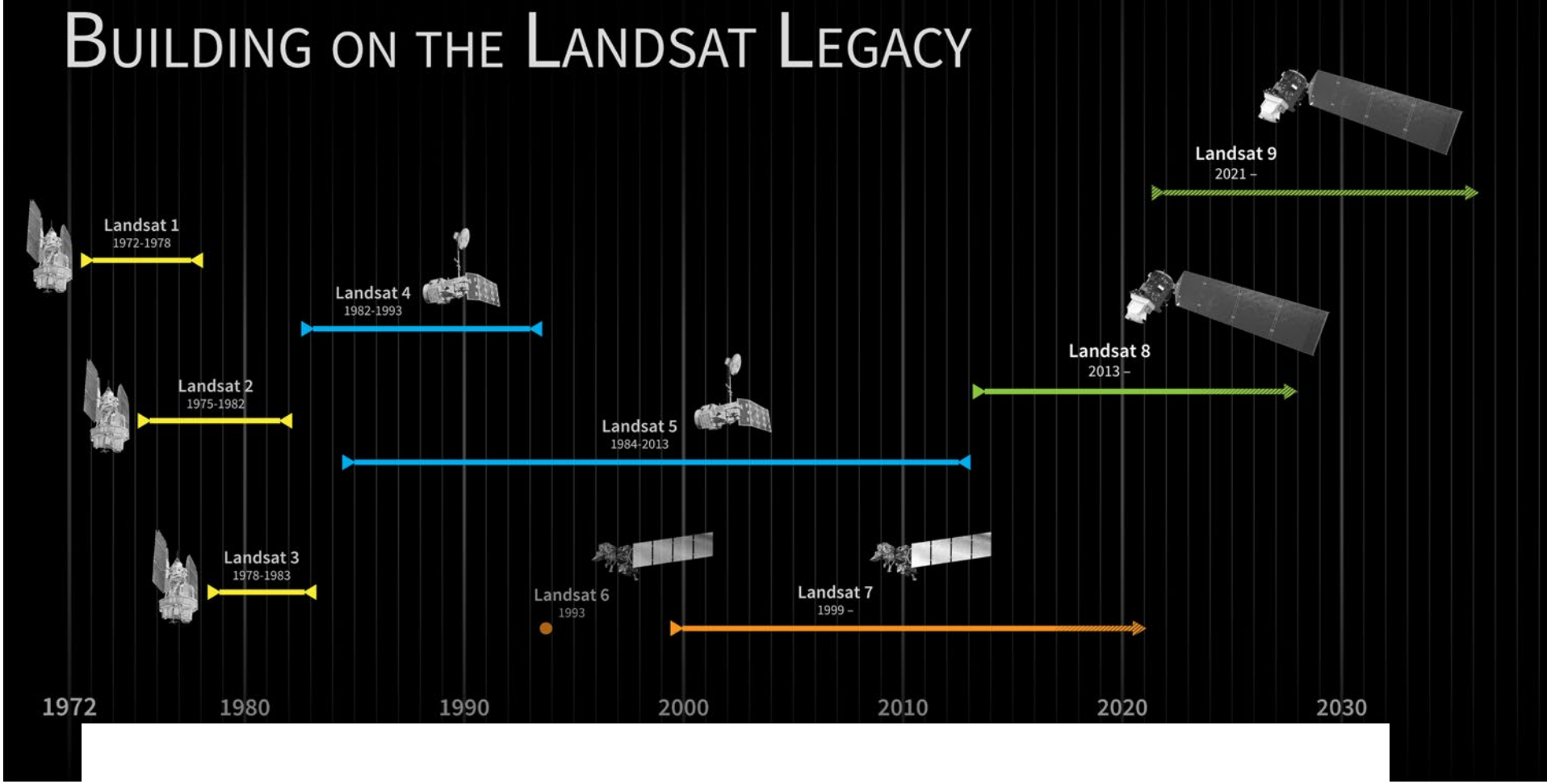
Students, 2008
Bangkok, Thailand

25 Years of Regional Programs: Summary of Accomplishments

The program has

- **advanced scientific analysis** to areas of the globe where LCLUC is taking place and provided insight into the various impacts of these changes
- **examined the underlying drivers** of land-use change including socio- economic, political, institutional aspects in diverse regions of the globe
- **evaluated the role of satellite data** in initiating projections of future regional land-use change
- **built broad networks** of international scientists that routinely utilize satellite data to monitor regional land-use change
- **fostered international collaboration** with regional scientists

The LCLUC Program has been the primary NASA user of Landsat data

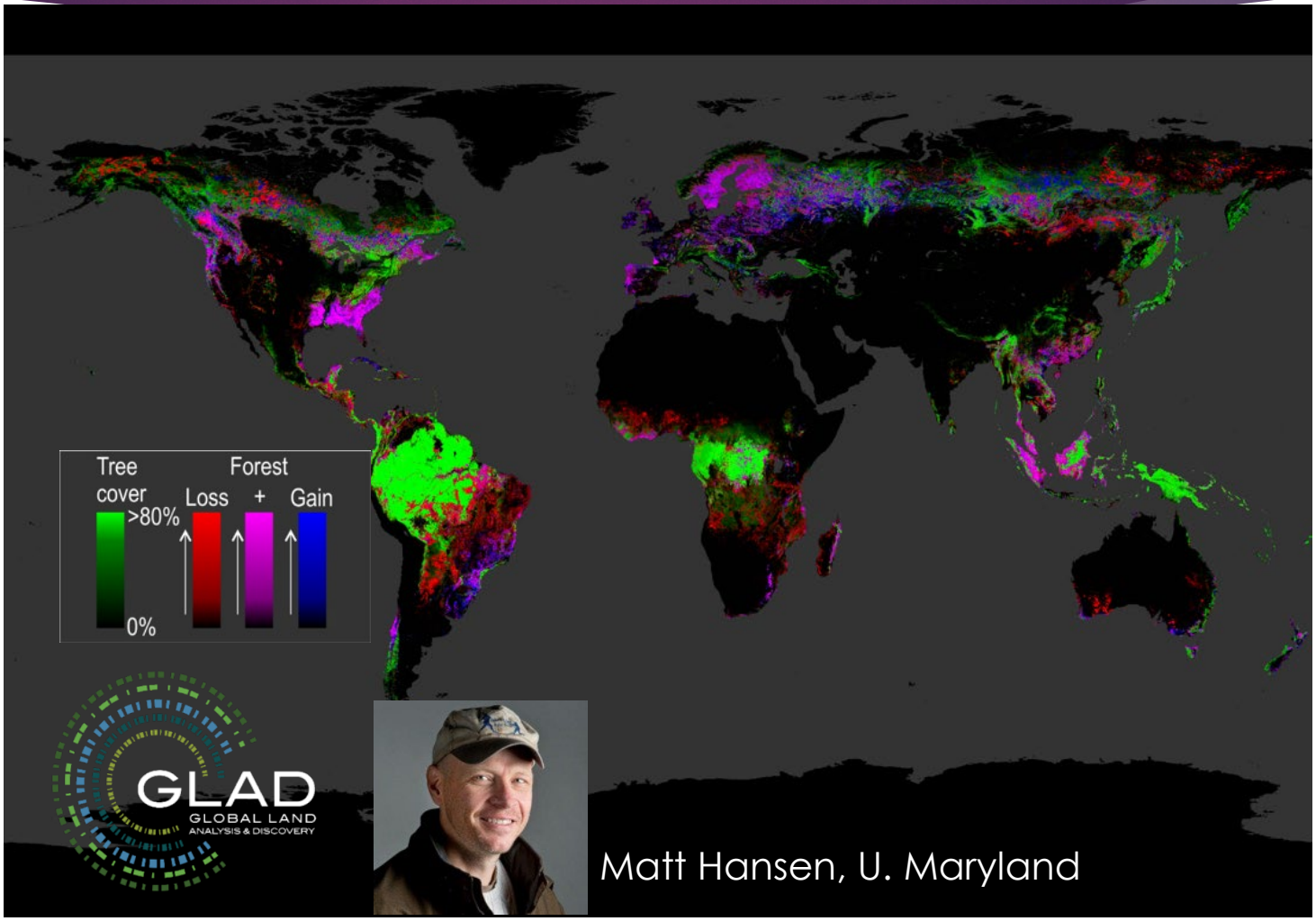


- **The Landsat program: Earth Resources Technology Satellites Program 1966, Landsat 1 (ERTS) launched in July 1972**
- **Thermal band added for Landsat 3 and beyond**
- **After launch, Landsat operations are transferred from NASA to USGS to collect, archive, process, and distribute the image data**
- **Until 2010 expensive, FREE NOW!**
- **Two-Landsat system frequency revisit time: 8 days -- in some areas may not provide enough observations for monitoring rapid changes (e.g., Ag) but sufficient for slow changes (e.g., Urban)**

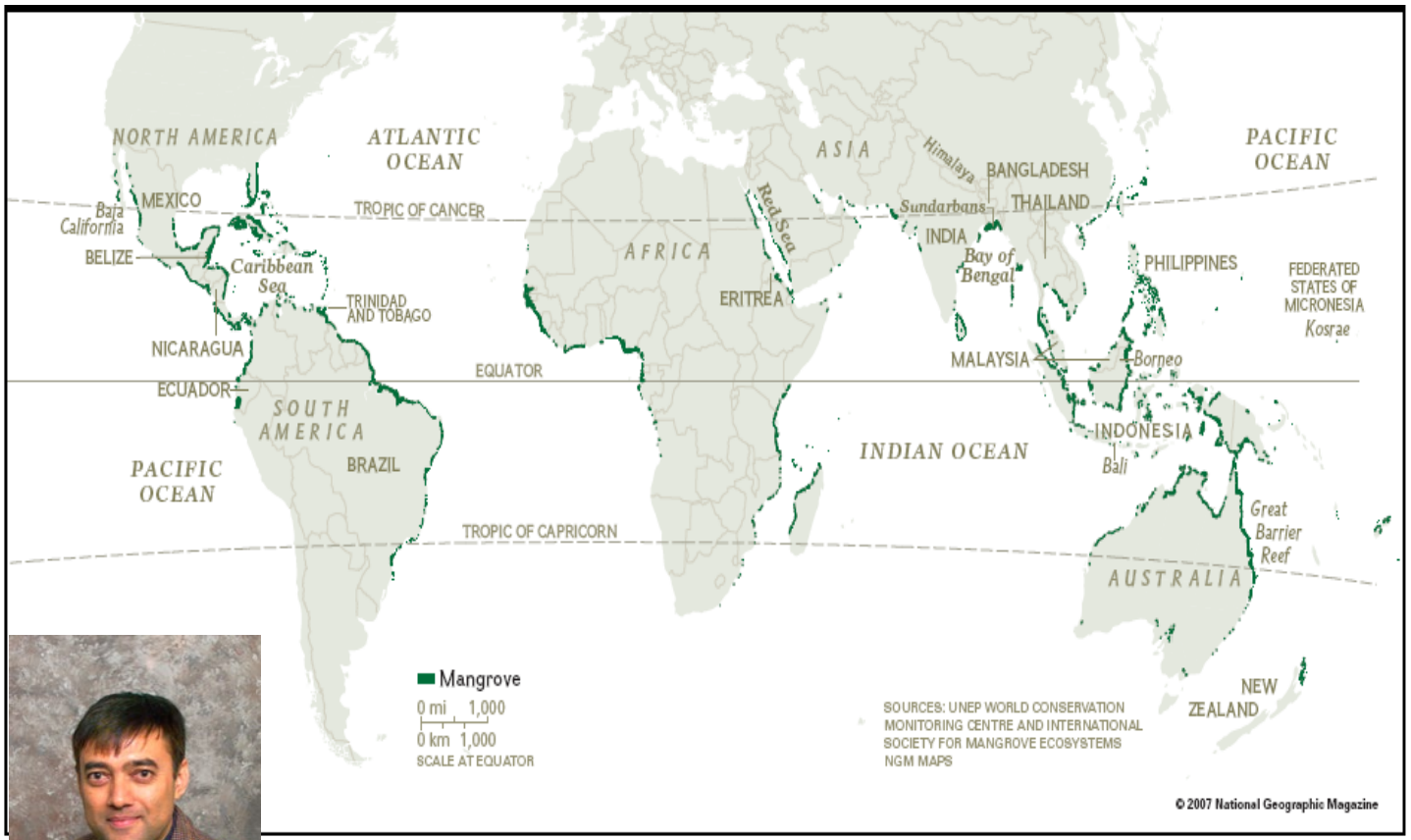
Products: Global Mosaic Using Landsat-7 and -5

David Roy, State Dakota State U. → Michigan State U.

Products: Tree Cover Extent and Forest Loss and Gain: 2000-2014



Products: Mangroves Extent



Chandra Giri, USGS → EPA

Products: Global cropland extent and change 2000-2020

Potapov et al.,, *Nature Food 2022*

Global cropland expansion in the 21st century

Global cropland dynamics 2000-2019

Global cropland dynamics 2000-2019:
- Stable cropland
- Intermittent cropland: 4/5 intervals
- Intermittent cropland: 3/5 intervals
- Intermittent cropland: 2/5 intervals
- Cropland gain in 2004-2007
- Cropland gain in 2008-2011
- Cropland gain in 2012-2015
- Cropland gain in 2016-2019
- Cropland loss in 2004-2007
- Cropland loss in 2008-2011
- Cropland loss in 2012-2015
- Cropland loss in 2016-2019

UNIVERSITY OF MARYLAND 18 56

25-Year of Global LCLUC Products: Summary of Achievements

The program has

- **provided the basis for monitoring**, reporting and verification of urban-, forest-, and agricultural cover change in the context of the implementation of Carbon Treaties
- **created the means to undertake periodic, continuous global assessments** of Land-Cover and Land-Use Change
- **quantified rapid changes** in the urban built environment, forest cover and agriculture around the globe
- **provided the primary science rationale** for the Landsat Mission and, more general, Sustainable Land Imaging
- **Provided proof of concept for** global Landsat-based products

Landsat Next -- Requirements Meet Emerging Needs

User need surveys provided a clear set of priorities for Landsat Next requirements to meet emerging needs at breakthrough effectiveness:

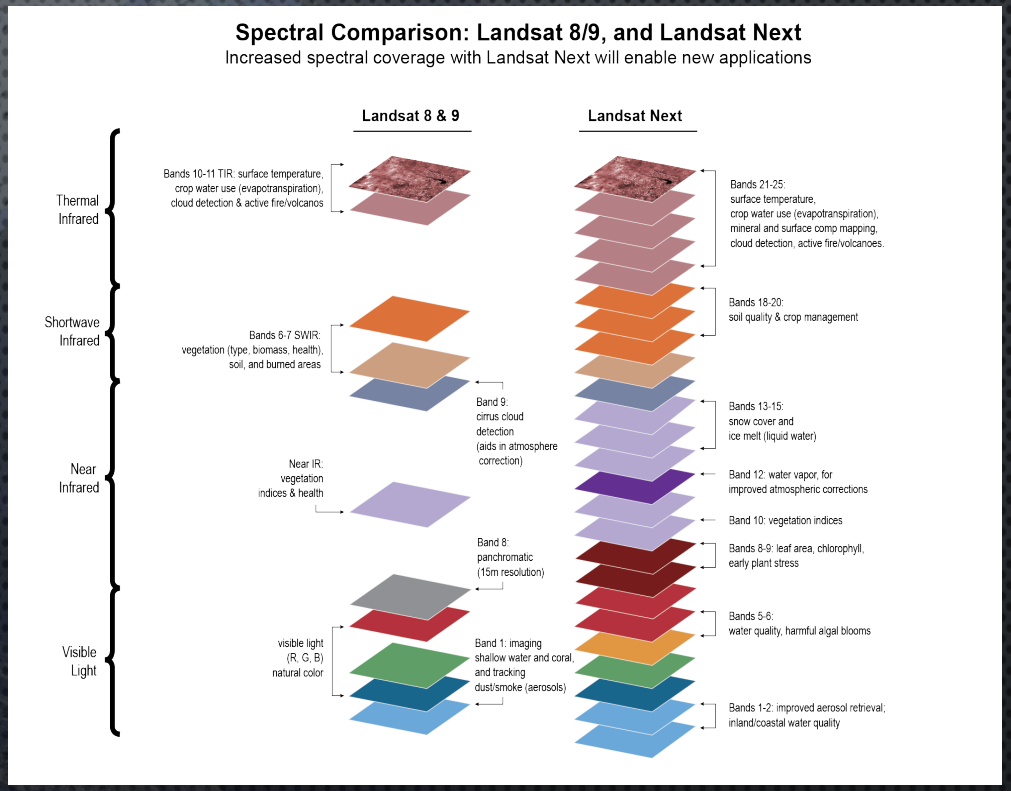
Improved Revisit Frequency. Dynamic phenomena (crop health & productivity, water quality, snow/ice state, wildfire) which require ~weekly clear views.

Higher Spatial Resolution. Experience with Sentinel-2 has underscored importance of 10-meter data for monitoring small agricultural fields, forest disturbance, urbanization, and other applications.

Additional spectral bands to support emerging applications in water quality, snow hydrology, soil mapping, and other areas.

Maintaining radiometric quality established by Landsat 8/9

Multi-spectral → Super-spectral



Landsat Next will provide more than twice as many spectral bands, with resolution improved by a factor of 2, and with the repeat coverage of Landsats 8 and 9, *combined*

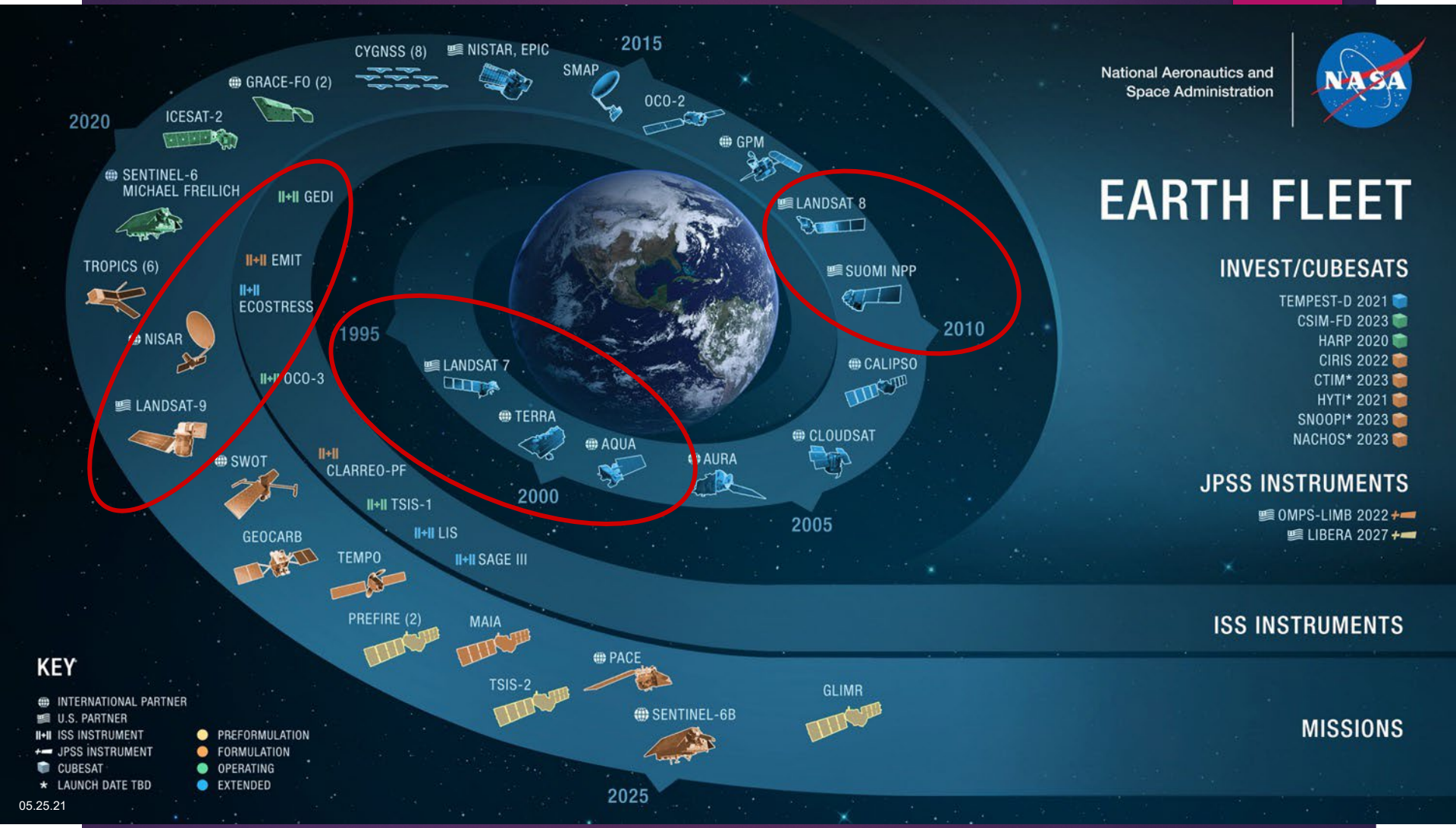
USGS

RFI Draft SLI "Superspectral" Requirements

- **RFI draft "superspectral" spectral bands**
  - Included Sentinel-2 bands
  - Added narrow bands for aquatic and cryosphere
  - Shifted SWIR bands for crop residue
  - Shifted/narrowed TIR bands for temperature/emissivity
  - Coastal aerosol at 30m for aquatic and mineral applications
- **Radiometric quality intended to match Landsat 8 OLI when aggregated to 30m**

	Band name	Ground Sample Distance (m)	Center wavelength (nm)	Band width (nm)	Rationale
1	Violet	60	410	20	Improved aerosol retrieval; CDOM from inland/coastal water
2	Coastal Aerosol	30	443	20	Landsat
3	Blue	10	490	65	Landsat
4	Green	10	560	35	Landsat
5	Orange	20	620	20	Phycocyanin detection for Harmful Algal Blooms
6	Red 1	20	650	20	Phycocyanin, chlorophyll
7	Red 2	10	665	30	Landsat
8	Red Edge 1	20	705	15	LAI, Chlorophyll, plant stress (S2)
9	Red Edge 2	20	740	15	LAI, Chlorophyll, plant stress (S2)
10	NIR Broad	10	842	115	10m NDVI (S2)
11	NIR1	20	865	20	Continuity (note – S2 narrower than L8)
12	Water vapor	60	945	20	Improved atmospheric correction for LST, SR (S2)
13	Liquid Water	20	985	20	Liquid water, surface water state
14	Snow/Ice 1	20	1035	20	Snow grain size for water resources
15	Snow/Ice 2	20	1090	20	Ice absorption, snow grain size
16	Cirrus	60	1375	30	Landsat
17	SWIR 1	20	1610	90	Landsat
18	SWIR 2a	20	2100	30	Subdivided for cellulose/crop residue measurement (Landsat)
19	SWIR 2b	20	2210	40	Subdivided for cellulose/crop residue measurement (Landsat/ASTER)
20	SWIR 2c	20	2260	40	Subdivided for cellulose/crop residue measurement (Landsat/ASTER)
21	TIR 1	60	8300	250	Mineral and surface composition mapping (ASTER)
22	TIR 2	60	8600	350	Emissivity separation, volcanos (SO2) (MODIS/ASTER)
23	TIR 3	60	9100	350	Mineral and surface composition mapping (ASTER)
24	TIR 4	60	11300	550	Surface temperature (Landsat), carbonates
25	TIR 5	60	12000	550	Surface temperature, snow grain size (Landsat)

2020



NASA is increasingly encouraging the use of international satellite data

HLS - making the combined use of multi-source moderate resolution data easier and more standardized

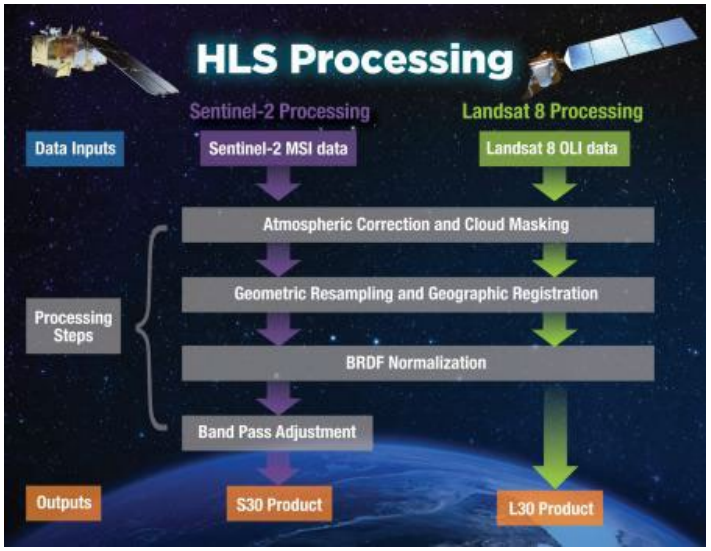
HLS Version 1.5 (Global HLS)

Global processing via NASA MSFC Interagency Implementation and Advanced Concepts Team (IMPACT) cloud computing project

- Forward processing started October 2020
- Back-processing to the beginning of the Landsat 8 and Sentinel-2 data records (2013 and 2015 soon, respectively); Plans to complete in 2023
- ESDIS compliant metadata, user guide, & ATBD
- Cloud Optimized Geotiff (COG) distribution format
- Earth Data interface for search/order GIBS interface for browse
- Unique aspect of HLS: processed, archived, and distributed on Amazon Web Services (AWS) commercial cloud
- Reducing from 2-week processing to 2 days

LP DAAC landing page:
https://lpdaac.usgs.gov/products/hlss30v015/

EDSC: https://search.earthdata.nasa.gov/search?q=HLS



Multi-Source Land Imaging (MuSLI)

Combining optical and microwave data: Landsat + Sentinel 2 + Sentinel 1

- Sentinel-2a: launched in Jun 2015
- Sentinel-2b: launched in Mar 2017
- Sentinel-1a: launched in Apr 2014
- Sentinel-1b: launched in Apr 2016
- Sentinel-1b: set for launch in 2023
- Landsat-7: launched in Apr 1999
- Landsat-8: launched in Feb 2013
- Landsat-9: launched in Sep 2021

Merging Sentinel-2 and Landsat data streams could provide < 5-day coverage required for Agricultural monitoring

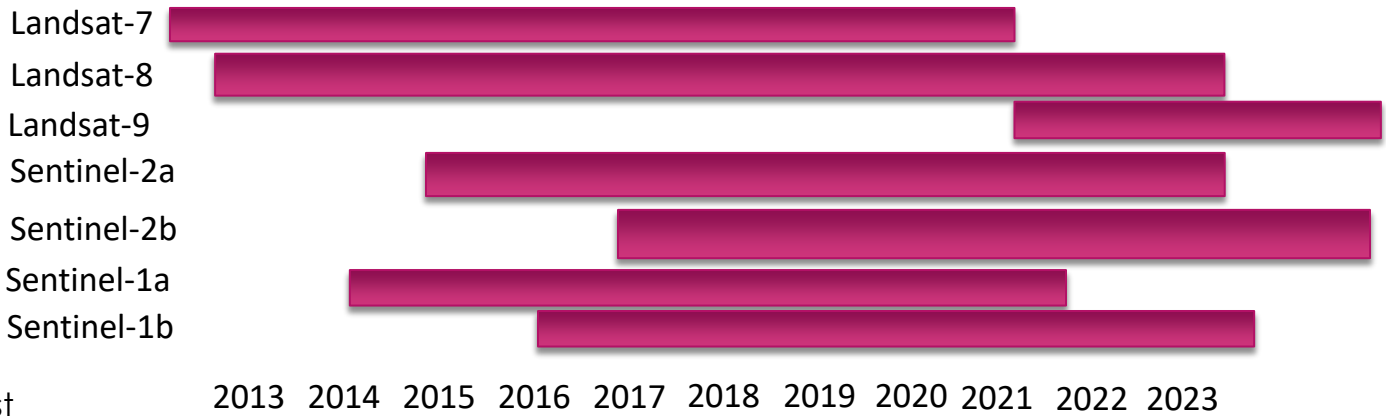
- Both sensors have 10-30m coverage in VNIR-SWIR
- Satellite orbits complementary
  - Landsat-8 & -9 8 days
  - Sentinel-2a & 2b 5 days
- Global ~3 day
- Merging in Sentinel-1 radar data provides all-weather microwave observations

Jeff Masek, NASA GSFC

MuSLI Project Scientist

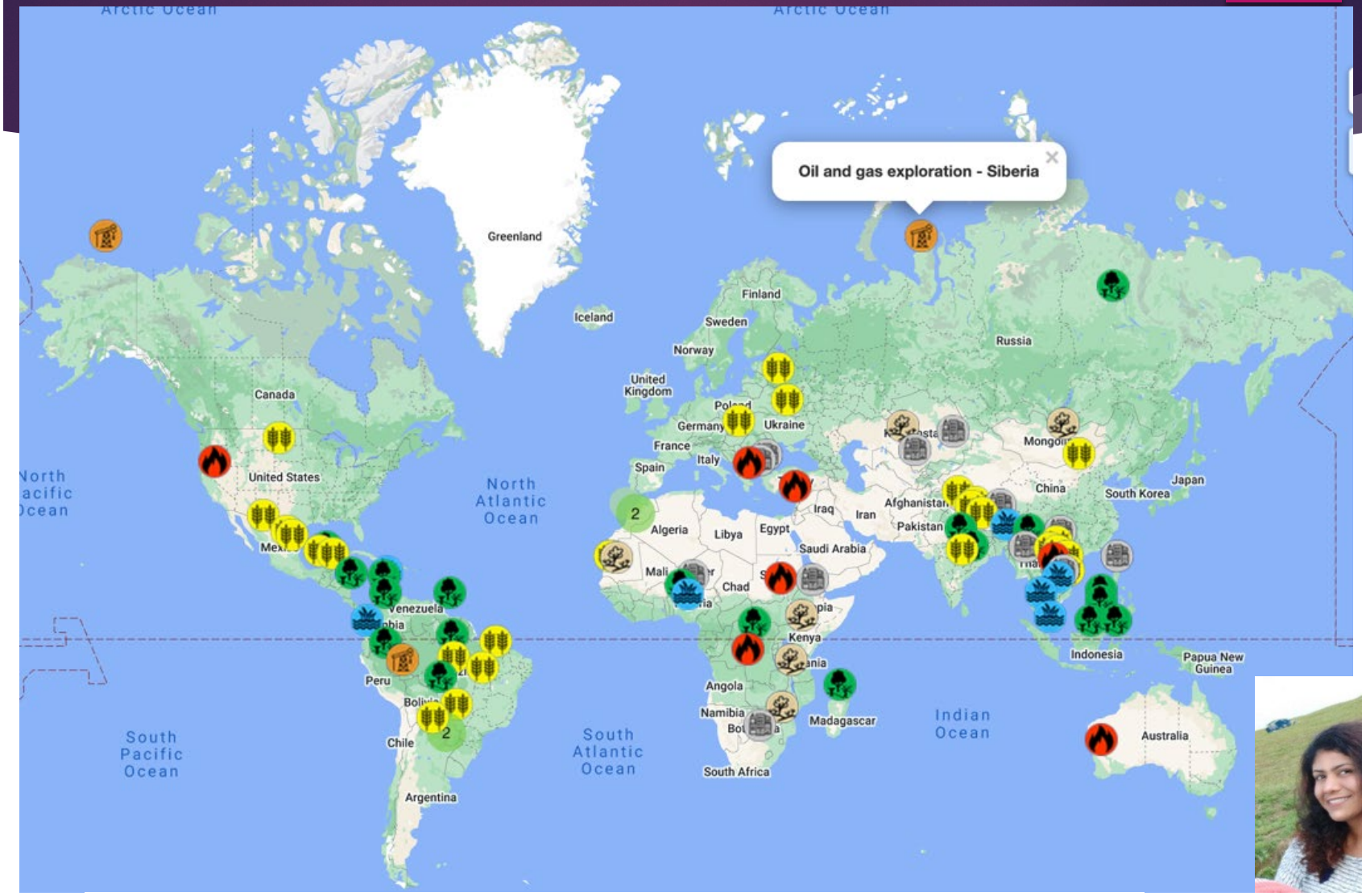
Landsat-9 Project Scientist

MuSLI ESA Project Scientist Benjamin Koetz,



MuSLI Solicitations: LCLUC-2014 (merging Landsat and Sentinel-2); LCLUC-2017 (incl. Radar data); LCLUC-2020 (incl. VHR data); LCLUC-2023 (incl. IR data and all of the above)

LCLUC Hotspots of Land Use



Meghavi Prashnani
LCLUC Program

ECOSTRESS: NASA Instrument on ISS

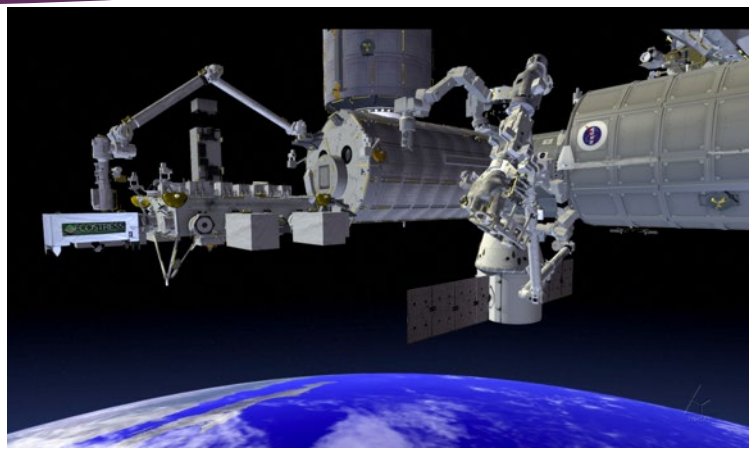
ECOsystem Spaceborne Thermal Radiometer Experiment on the International Space Station (ISS)

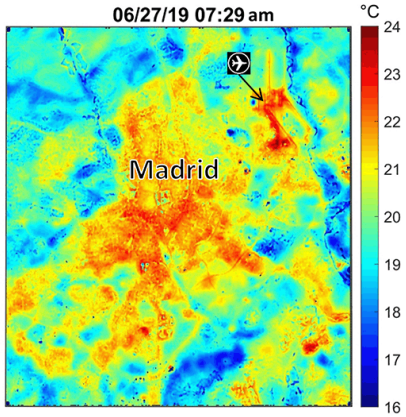
- Prototype HyspIRI **Thermal Infrared** Radiometer

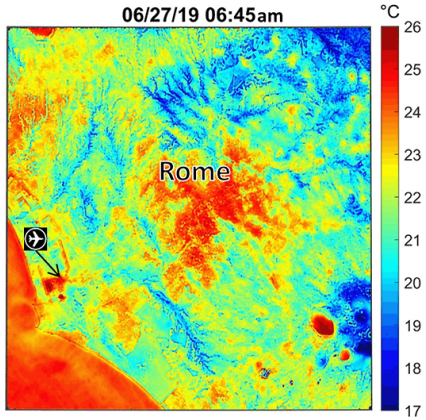
  5 spectral bands in the 8-12.5 µm range +1.6 µm

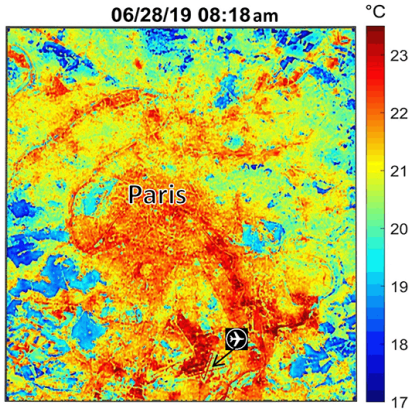
  - Spatial resolution ~70 m
  - **Advantage** over ASTER (on TERRA) – more frequent revisiit

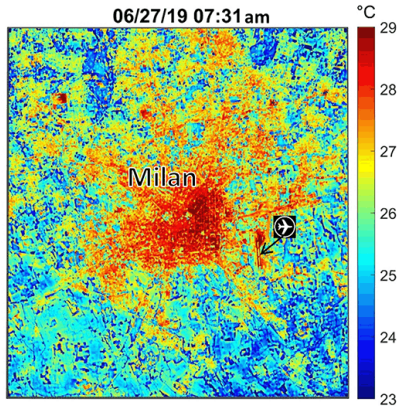
- Science objectives
  - Identify critical thresholds of water use and water stress in key biomes (e.g., tropical/dry transition forests, boreal forests)
  - Detect the timing, location, and predictive factors leading to plant water uptake decline and cessation over the diurnal cycle
  - Measure agricultural water consumptive use over CONUS at spatiotemporal scales applicable to improving drought estimation accuracy











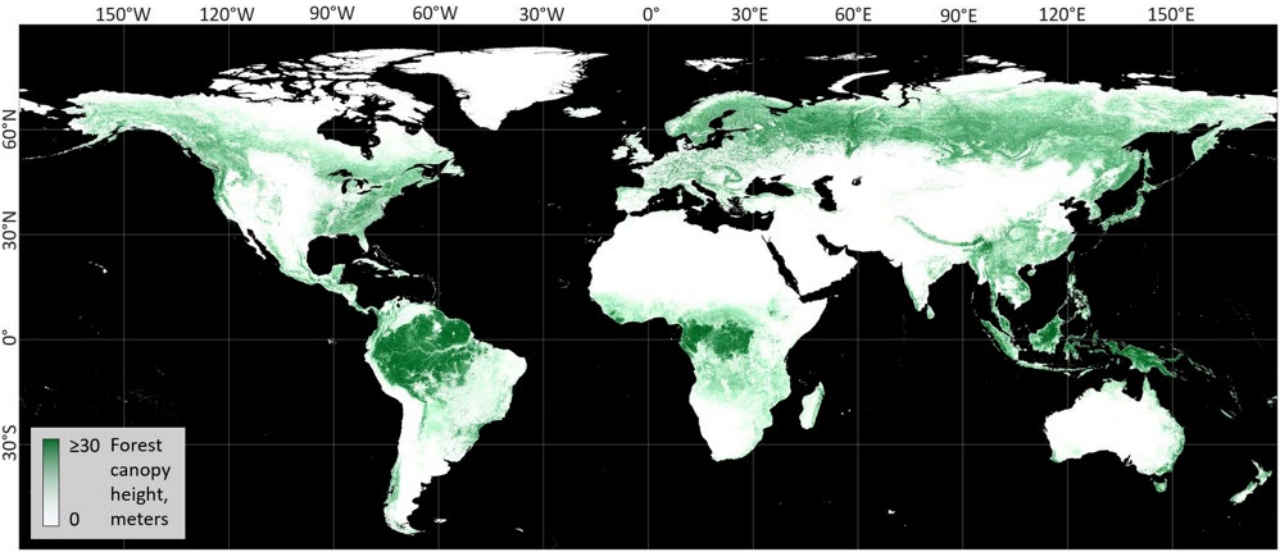
NASA Global Ecosystem Dynamics Investigation (GEDI) mission

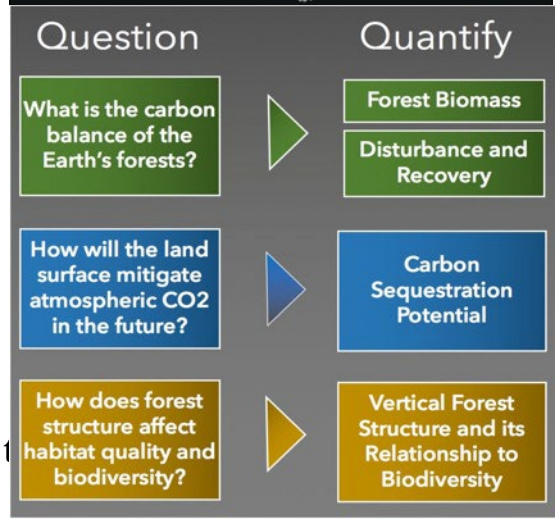
High resolution laser ranging observations

- three lasers produce eight parallel tracks of observations
- each laser fires 242 times per second and illuminates a 25 m spot (a footprint) on the surface

GLAD Global Land Analysis & Discovery

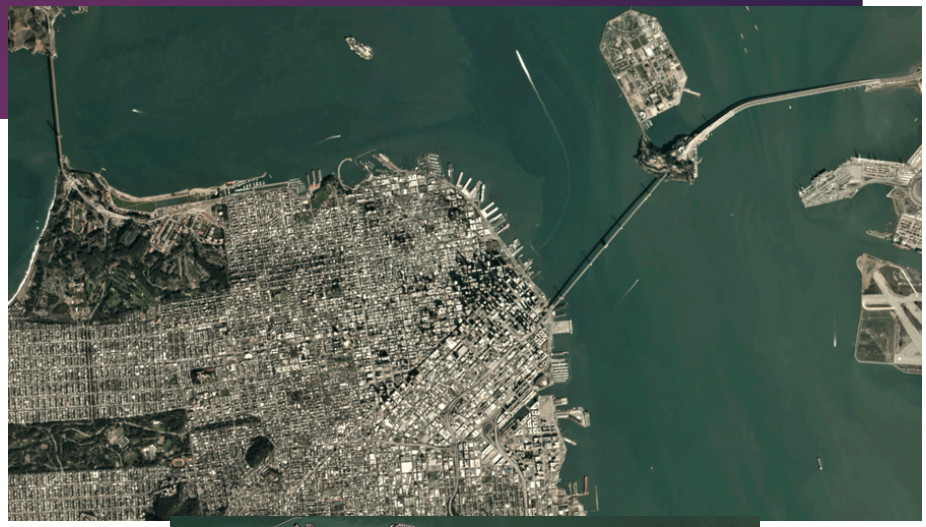
Global Forest Canopy Height: 2019

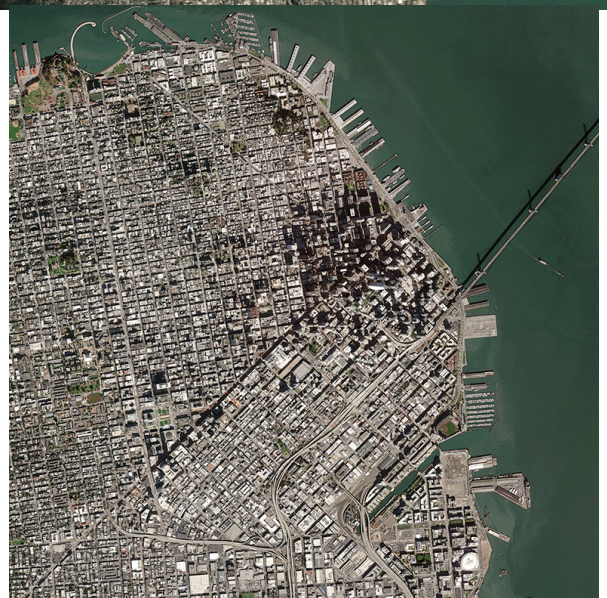




Integration of the GEDI lidar forest structure measurements and Landsat analysis-ready data time-series Potapov et al. 2020, RSE

Zooming-in to higher spatial resolutions





Commercial satellites offer images at fine spatial scale and high temporal resolution

- The first NASA Data Buy 2003 – Ikonos
- Planet Labs constellation (>200 sats) acquire daily images of the Earth with 3-m resolution
- Maxar (Digital Globe, WorldView) with 1m resolution
- NASA Commercial Smallsat Data Acquisition (CSDA)
- Limited Planet datasets are available for free at Universities
- Wall-to-wall VHR data over tropics purchased by the government of Norway (to tackle tropical deforestation)
- **Special Issue in Remote Sensing (2020) on applications of VHR data in LCLUC studies**

25 Years of Community Outreach

LCLUC@UMD.EDU

- **Quarterly e-Newsletter**
  - E-Newsletters: 11
- **PR, media**
- **Facebook, twitter, linkedin**
- **Website**
  - **Mapper**

LCLUC Webinars

- Presentations: 92
- Started in 2014
- Total: 17 series
- Intensified in 2020
- Topical or regional

LCLUC Urban and Agriculture Hotspots Webinar Series - 2022

- **Total 21 SARI Webinars.**
- **Total 1845 individual participants from 117 countries**

LCLUC Forest Hotspots Webinar Series - 2022

Objectives for this International Meeting

1). Review GHG and SL Climate Pollutants emission estimates and methodologies from different sources including biomass burning in the Asian region;

2). Understand the impact of GHGs and aerosols on local climate, including health impacts;

3). Explore the potential of satellite remote sensing datasets for quantifying pollutants, aerosols, and pollution episodes;

4). Review modeling approaches for characterizing emissions;

5). Strengthen the regional information exchange and training activities through effective collaborations.

Meeting Sessions

Keynotes (20 mins), Technical (15 mins) + allow 5mins questions

- Day 1:
  - Session I: Inaugural session
  - Session II: Programmatic Presentations
  - Session III: GHG and Pollutant Emission Inventories including Decision Support Systems
- Day 2:
  - Session IV: Land Use and Emissions
  - Session V: Air Pollution Impacts and Health
- Day 3:
  - Session VI: Aerosol Pollution
  - Session VII: Biomass Burning Emissions
  - Discussion Session – Research Needs and Priorities